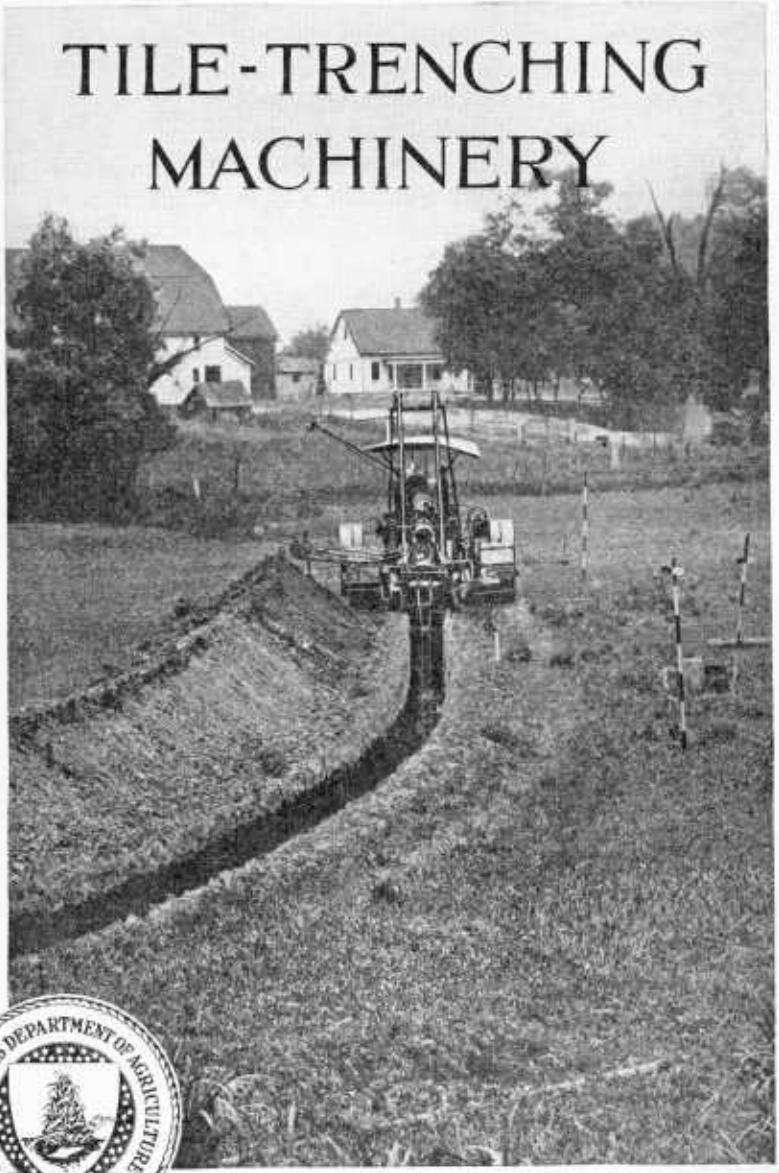
U. S. DEPARTMENT OF AGRICULTURE

FARMERS' BULLETIN No. 1131

TILE-TRENCHING MACHINERY



THE MORE EXTENSIVE use of tile-trenching machinery has been brought about by the rising prices and increasing scarcity of labor and the rapid extension of tile drainage for farm lands to increase crop production.

Tile-trenching machinery may be divided into two general classes—horse-drawn ditching plows and power-operated trenching machines.

The ditching plows are comparatively inexpensive implements, costing from $50 to $300, which will excavate trenches suitable for the smaller sizes of tile. Hand labor is necessary to grade the trench after using them.

Power operated machines are of the following general types: Wheel excavators, endless-chain excavators, and those of the drag-line and shovel types. The less expensive power machines, costing from $3,300 to $4,500, are used extensively on farm tile drainage. The larger sizes are adapted to contractor's use.

Devices for back-filling trenches range from the ordinary moldboard plow to power-driven back fillers.

The cost of trenching by machinery is not greatly different from that of handwork. The main advantages of machine work over hand labor are the fewer men required and the more rapid completion of the work.

Washington, D. C.

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The names and addresses of the manufacturers of the various machines discussed in this bulletin will be furnished on application to the Bureau of Public Roads, Department of Agriculture, Washington, D. C.

TILE-TRENCHING MACHINERY

By D. L. YARNELL, *Senior Drainage Engineer, Division of Agricultural Engineering, Bureau of Public Roads*

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THE INVENTION of suitable appliances for tile trenching has been stimulated by various agencies—the rising prices and increasing scarcity of labor, the rapid extension of tile drainage for farm lands to increase crop production, and the growing practice of using large tile instead of open ditches of moderate size for community outlets, especially where the depth of cut is rather great. Where trenches are dug by hand deeper than 5 feet, the material must be handled at least twice, since the dirt can not be thrown back from the edge of the trench at the first handling. Besides reducing the amount of cost of labor, a good machine greatly lessens the time necessary for doing the work, which is often of considerable advantage, apart from any saving in direct money cost. Difficulties such as occasionally arise where many unskilled workmen are employed may be largely avoided by the use of machinery requiring only a small crew. The many types of equipment for trenching vary from horse-drawn machines of small size to elaborate power-driven machines costing thousands of dollars. The various types of ditching plows are limited as to the depth and width of trench they will cut, also in regard to the conditions under which they will work.

REQUISITES OF A GOOD MACHINE

Three things are required of a good trenching machine, namely, (1) it must operate efficiently through various kinds of soil; (2) it must be capable of cutting true to grade; (3) it must work for long periods without breaking or otherwise getting out of order. The first of these requirements is the hardest to fulfill; the second is the easiest.

There are many kinds of soil to be encountered—hard shale, cemented gravel, sand, stones, loose loam, soft muck, and sticky clay. None of the machines will handle solid rock. The ideal machine will handle all kinds of soil, with but minor changes of parts, without breaking or stopping and at a minimum expense for purchase, operation, repairs, and depreciation. Open or skeleton excavating

buckets are best suited to sticky soils, while solid buckets are necessary in loose, dry soils, though some machines have efficient cleaning devices that permit the use of solid buckets for any kind of material. A machine must be strong to work through shale or stony ground, but if increased strength entails added weight its efficiency and adaptability may be affected. A heavy machine can not work over soft ground unless fitted with rather costly apron tractors instead of the driving wheels.

GENERAL CLASSES OF TRENCHING MACHINES

The many types of trenching machines may be divided into four general classes: (1) Plows, (2) wheel excavators, (3) endless-chain excavators, (4) scraper excavators. The general nature of the plows is indicated by their names. They are operated by horses or tractors. In the wheel excavators the excavating buckets are arranged upon the rim of a wheel. (Fig. 3.) In the endless-chain excavators the excavating buckets are carried on parallel endless chains supported by a long steel frame at the rear of the machine. One end of the frame is lowered so that the buckets are drawn up the end of the trench, cutting a thin slice of earth from the bottom to the top. (Fig. 7.) The scraper machines are the same as the drag-line machines designed for wide ditches, sometimes with slight changes in the rigging to give better control of the bucket.

Power shovels are of the type ordinarily used in the construction of open ditches. The largest machines of the third and fourth classes are adapted to deeper and wider trenching than are those of the other classes.

In the following descriptions of the various types the letters used to designate the machines have been assigned arbitrarily by the writer for convenient reference. The prices given are those quoted during the spring of 1930.

DITCHING PLOWS[1]

This class of excavators has been made to include the smaller and less expensive implements, which will be found economical for smaller jobs than would warrant the purchase of the more costly machines. All the plows are lacking in any device for cutting accurately to grade. Some handwork is necessary to make the trench smooth for laying the tile properly. Many are limited in depth of digging to 2½ or 3 feet, which in many places is not as deep as tile should be laid. Some of these implements are merely aids to handwork, using power only to loosen the dirt. The main advantage over the more elaborate trenching machines is their low cost.

The ditching plow is essentially a farm tool, adapted to the needs of the farmer who wishes to drain a portion of his farm. By using plows he can to a certain extent substitute power for labor. If the drains are so located that they can be constructed at times when farm work is not pressing, the horses unemployed, and the farm labor free to do most of the handwork, the tiles can be laid quite cheaply. For large jobs, or contract work, power ditchers are probably preferable.

[1] The data on horse-drawn plows have been abstracted from a report by F. F. Shafer, formerly associate drainage engineer, Bureau of Public Roads.

The ditching plows will not work on lands so wet or boggy that horses or tractors can not be driven over them. In wet, loose, or sandy soils it may be necessary to use extra wide eveners that the horses may walk some distance away from and on each side of the trench, and thus the banks of the trench are not so apt to be broken down. Attempts to use tractors for operating ditching plows have in some instances failed because the weight of the tractor broke down the banks of the trench.

In constructing tile drains it is always desirable to open up only a comparatively short length of trench at one time, for if bad weather occurs the walls of the trench are apt to cave or wash, and much

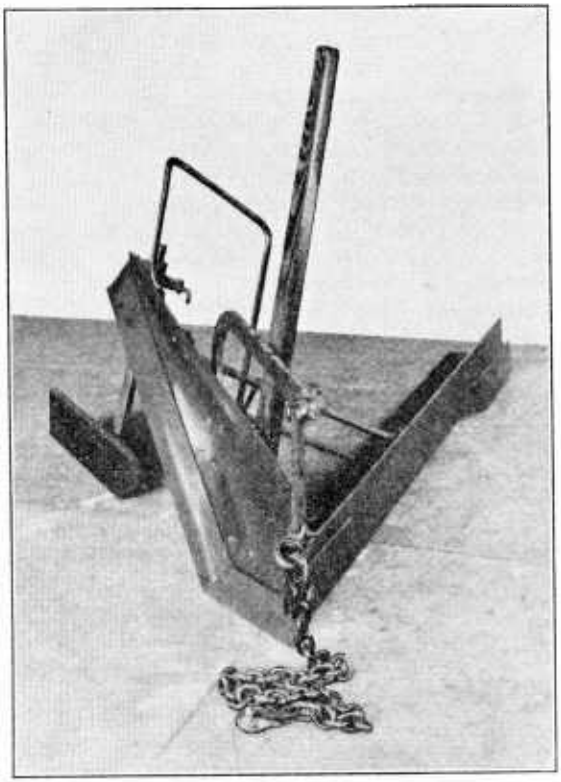

FIGURE 1.—Ditching plow A for opening up tile branches

additional labor will be required to get the trench in condition to lay the tile. If, however, the plow is to be used to the best advantage, it is necessary to open up the entire length of a drain, or possibly several drains at one time. Tile should always be laid and blinded as fast as the trenches are finished to grade.

DITCHING PLOW A

This plow (fig. 1) is a simple implement designed for opening up a shallow, flat-bottomed ditch which must be finished to grade by hand labor before laying the tile. Its maximum cutting depth is

about 18 inches, and the ditch will be about 10 inches wide on the bottom and 24 inches wide at the ground surface. In light soils the plow can be pulled by a 2-horse team. It weighs 380 pounds and sells for $55. This machine can be used also for grading and digging small, open ditches.

WHEEL EXCAVATORS

COMMON FEATURES

The wheel excavators generally have steel bed frames, rigidly braced, upon which the power equipment is mounted. Internal-combustion engines burning gasoline, kerosene, or crude oil are generally used.

The machine usually is supported upon two pairs of wheels, the front pair with flanges to prevent slipping sidewise from the line of the trench. The rear wheels carry most of the weight and therefore are large and broad in the form known as apron or caterpillar tractors. (Figs. 3, 5, and 6.) Each of these tractors consists of a series of wooden or iron crosspieces carried by parallel endless chains about a steel frame in such manner that the weight of the machine rests upon several crosspieces; the large bearing surface thus obtained will support the machine upon very soft ground. As the excavator moves forward the chains lift the crosspieces at the rear and carry them to the front of the tractor.

Most machines move by applying power directly to turn the rear tractors. In soft soils, when power is applied to the tractors, these often slip and the consequent "churning" causes the trench banks to cave and the machines to settle deep into the ground. When a tile-laying shield must be used the amount of power necessary to move the machine may cause a great deal of "churning," in which case it may be advisable to pull the machine ahead by a cable anchored to a "dead man." By pulling the machine ahead the load on the ditch bank is decreased, which may prevent caving of soft soils.

The digging is done by buckets upon the rim of a wheel that is revolved in the trench (fig. 2), and as each bucket reaches the top of the circle the dirt falls upon a conveyor belt that can be shifted to deposit the soil upon either side of the trench.

Levers are so arranged that the depth of excavation can be accurately controlled by the person operating the machine. An arm or gage is attached to the digging frame in such a way that the operator can sight across it to targets set along the line of the trench at a known height above the desired bottom, and can thus cut true to grade.

For work in soils so soft that the sides of the trench will not stand unless supported, some machines may be fitted with shields following close behind the digging apparatus, which keep the trench open until the tile can be placed in position. The shields for the smaller machines are usually about 8 feet long, just sufficient to permit a man using a tile hook to lay the tile properly. The use of the shield, of course, increases the amount of power necessary to draw the machine ahead. The caving earth frequently causes the last-laid tile to "creep" forward with the machine, leaving an opening between tiles where much dirt might get into the drain and choke

it. To prevent this creeping, the man laying the tile must hold the tile in place until it has left the shield. The shields on the large machines are of sufficient width for a man to work in them.

Unstable soils often cave in at the sides of the digging wheels. To prevent this the manufacturers provide a casing for the digging wheel. The additional cost of such a wheel casing is often justified, since it prevents the earth from caving into the trench at the wheel.

MACHINE B

The machine of this class in most common use (fig. 3) has an open excavating wheel; that is, a wheel with neither spokes nor hub. This wheel consists of two parallel iron rims held in their proper relative position by the buckets, which are fixed between the rims and firmly riveted to them. The rims are supported upon four pairs

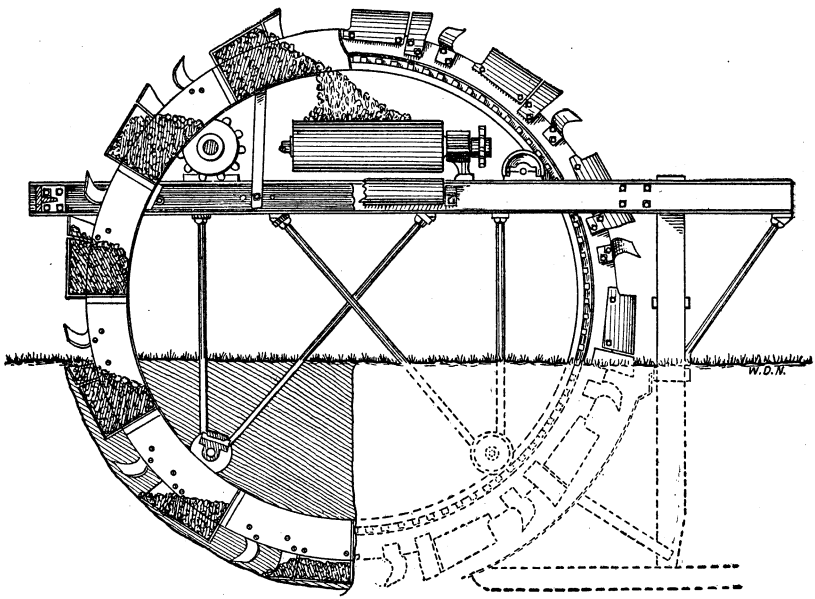

FIGURE 2.—Digging mechanism of a common type of wheel excavator

of small wheels. (Fig. 2.) Both wheels of the pair just above the point where the digging is done are sprocket wheels, through which the power is applied. The buckets are open at the inner side, but close inside the rims is a metal plate extending nearly one-half the circumference of the excavating wheel that keeps the dirt in the buckets until it has been carried to the highest point; there it falls upon a belt conveyor, which deposits the soil beside the trench. Between the buckets, which have semicircular cutting edges, side cutters (fig. 2) are bolted to the wheel for cutting the trench a little wider than the buckets, thus reducing the friction. The front end of the frame carrying the excavating wheel is hinged to the rear of the platform carrying the power equipment; the rear of the frame is supported on a shoe that slides on the bottom of the trench and makes a smooth, shallow groove for the tile. The maximum depth of digging is about two-thirds the diameter of the wheel.

Solid buckets are used for digging light or sandy soils and skeleton buckets for the wet and sticky soils, as the latter buckets are easier to clean. A cleaning device is furnished to remove sticky earth from the buckets.

This machine is made in two sizes, one, which cuts to a maximum depth of 4½ feet, and another which cuts to 5½ feet. By using an extra set of buckets the normal width of trench, 11½ inches, can be increased to 14½ inches on either machine. The larger machine, equipped with the 5½-foot cutting wheel and apron, and crawler type rear traction, has an operating weight of about 20,000 pounds and sells for about $3,600. The smaller machines weighs 14,000 pounds and sells for about $2,800.

The machine is equipped with various gears for regulating the forward movement, which is accomplished by power applied to the rear wheels of tractors. The road speed is about 2 miles an hour. For railroad transportation the wheels or tractors must be removed from the larger sizes.

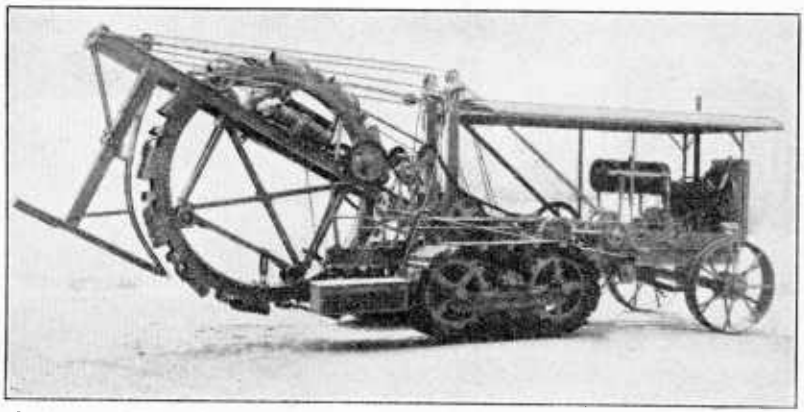

FIGURE 3.—Wheel machine B equipped with a 4-cylinder, internal combustion engine, and apron wheels. This size of machine cuts a trench 11½ inches wide, 5½ feet deep at one operation

The cutting speed of these machines varies from 2 to 8 feet per minute. In beginning a trench the forward end of the cutting-wheel frame should be about 3½ feet lower than the rear end. The traction is then thrown in, and as the machine moves forward the wheel cuts its way forward and downward at this angle until grade is reached. The digging-wheel frame is leveled and grade is maintained by raising or lowering the forward end of the frame by a power hoist. The smaller machines are provided with a friction safety device which slips when an obstacle is met. On the larger machines the multiple-disk clutch forms the safety device. A sight arm is provided for digging to grade. A careful operator can attain very satisfactory grades with this machine. One man is required to operate it.

A large number of these machines have been manufactured and have given general satisfaction under ordinary soil conditions. They have cut tree roots as large as a man's arm. Stones larger than the buckets will be rolled out if found near the surface of the

ground, but when bedded deeply they must be removed by hand. Ordinarily it is not wise to attempt to cut large roots or remove large stones with the machine, as it strains it unnecessarily.

ENDLESS-CHAIN EXCAVATORS

This class of excavator, like the wheel machines, has a steel bed frame mounted upon two pairs of wheels and carrying an internal-combustion engine. The digging apparatus is operated by a wheel

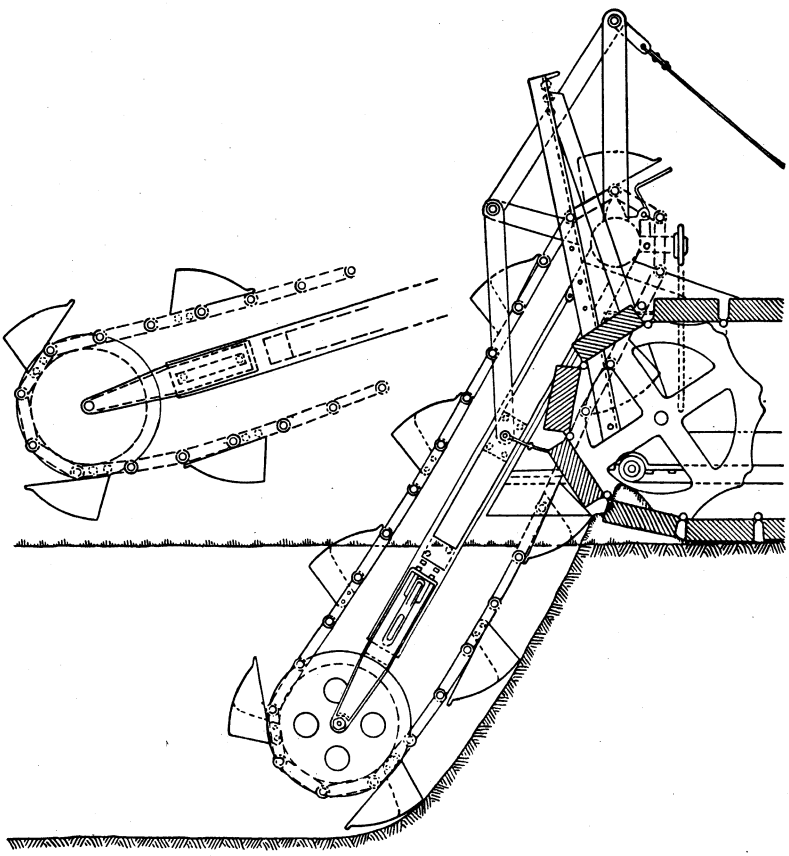

FIGURE 4.—Digging mechanism of a common type of endless-chain excavator

at the upper end of the frame, receiving power through a chain or belt drive from the engine. (Fig. 4.) At the end of their upward movement the buckets empty their loads upon an endless belt, which conveys the dirt far enough to the side that it will not fall back into the trench. Cutting knives or teeth on the lip of the bucket are often used in hard ground.

Devices for cleaning the buckets are provided. The depth of excavation is regulated by levers in the same way as for the wheel excavators. Shields can be used to keep the trench from caving until the tile have been laid.

MACHINE C

This endless-chain trenching machine (fig. 5) will excavate from 15 to 42 inches in width and any depth down to 7 feet. It has a traveling speed of 1½ miles per hour and 16 digging speeds of from 7 inches to 9 feet 4 inches per minute. The reversible conveyor can be shifted through the machine for depositing the excavated material on the other side of the trench while the machine is digging. It is mounted on full multiplane traction, which simplifies moving the machine in close quarters and also allows the machine to travel over soft ground. The bearing pressure is 6½ pounds per square inch. The 4-cylinder motor is rated at 45 horsepower and 1,000 revolutions per minute. The boom can be shifted off center to either side of the machine so that it is possible to dig a trench within a few inches of any obstruction. The boom operates at a slope of 45°, the digging being entirely behind the multiplanes and,

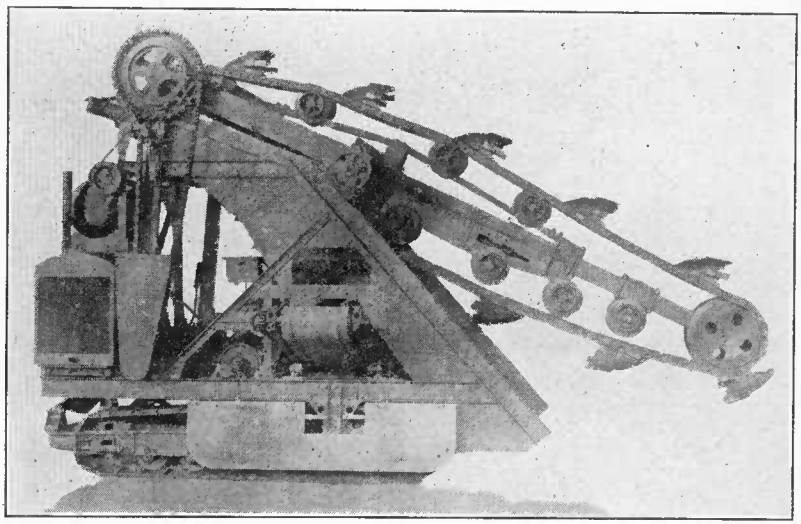

FIGURE 5.—Machine C, endless-chain type

it is said, the machine consequently can dig through unstable material without danger of the weight of the machine causing it to fall into the trench. The machine weighs 20,000 pounds.

MACHINE D

This excavator (fig. 6) is designed with a low center of gravity and large bearing surfaces which enable it to work readily over soft or uneven ground. The power plant is a standard make of tractor engine. Nine forward and three reverse speeds, ranging from 70 feet to 3¼ miles per hour, are provided. Excavator buckets can be had with cutting widths ranging from 13 to 30 inches. The buckets are individually self-cleaning and are said to discharge all kinds of material. The cross conveyor, for depositing the dirt at the side of the trench, is reversible and automatically levels itself, regardless of the position of the ditcher boom. The maximum digging depth is 7½ feet. The machine weighs about 19,000 pounds and sells for from

$5,565 to $6,125, depending on the size of buckets and amount of extra equipment included. Wider treads, lighting sets, and other extra equipment can be obtained at additional costs.

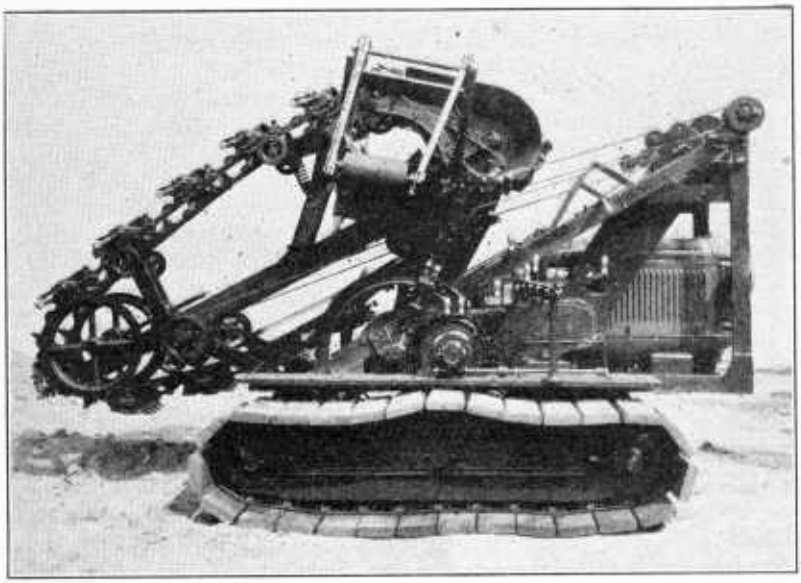

FIGURE 6.—Machine D, endless-chain type

MACHINE E

A type of endless-chain excavator (fig. 7) with a vertical boom is now being made in sizes suitable for large-scale farm-drainage opera-

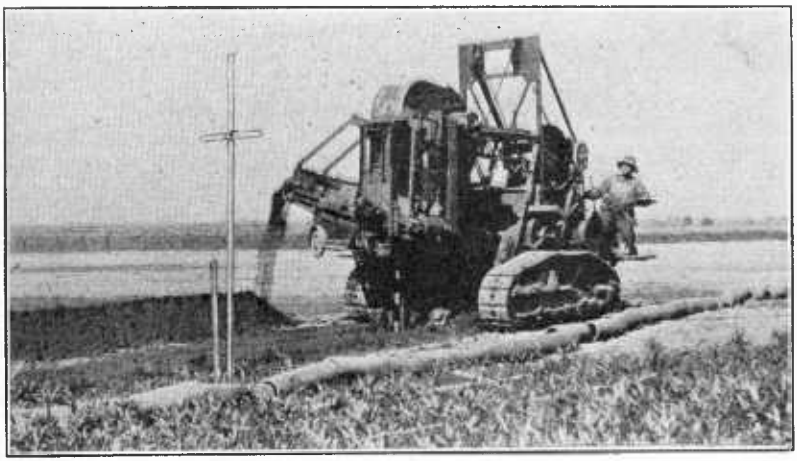

FIGURE 7.—Machine E, endless-chain type with vertical bloom

tions. The digging apparatus, instead of excavating the material from a sloping face, digs in a vertical position. This method of excavating does not require a long digging boom; thus the machine

is somewhat lighter in weight than other machines capable of digging the same size of trench. The excavator is mounted on two crawlers, each 14 inches wide by 7 feet 6 inches long, giving a bearing pressure of 7½ pounds per square inch for the standard-size machine. Power is furnished by a 4-cylinder gasoline engine developing 41 horsepower. Digging booms are furnished for excavating trenches from 10 to 24 inches wide, at depths up to 7 feet. Digging speeds vary from 1 to 10 feet per minute, depending upon soil conditions. A road speed of 2 miles per hour is obtainable. The weight of the machine is approximately 16,000 pounds. For excavating in soil which caves badly a shield is provided which permits a man to lay tile immediately behind the ditcher. A special arm is provided which enables the operator to sight along his grade targets and keep the machine digging at an accurate grade. This machine costs from $4,000 to $6,000, depending on size and equipment.

SHOVEL EXCAVATORS

MACHINE F

For digging trenches for large outlet drains a type of machine similar to machine F (fig. 8) is quite generally used. This particular machine is equipped with a trench hoe, but it, and other makes of similar machines, may be arranged to use either a shovel, clamshell, or drag-line bucket. Equipped with a drag line, it can be used for back filling. The machine is 13½ feet long, 8 feet wide, and is equipped with full crawler traction, 10½ feet long. It will cut a minimum width of ditch of 18 inches and to a maximum depth of 12½ feet. The hoe can be swung through 270°, which is a three-quarter swing. The machine has three travel speeds, ranging up to 4 miles per hour. It weighs 20,500 pounds and, equipped as shown, sells for about $5,200.

BACK-FILLING DEVICES

For back filling the trench both horse-drawn and power-operated implements may be used. For the smaller and shallower trenches the common method is by means of an ordinary moldboard plow. (Fig. 9.) The V-shaped drag operated by horses may also be used. By driving back and forth along the trench the material is dragged back into the point of the drag and drops into the trench. The common slip scraper is occasionally used to back-fill trenches. A road grader or steel-bladed scraper (fig. 10), which is mounted on wheels and pulled by horses, may also be used. This machine costs about $75.

For filling large trenches power-operated back-filling machines are rapidly coming into use. One type is shown in Figure 11. This machine travels along one side of and parallel to the ditch. When all the material at one place has been deposited in the trench the machine moves ahead directly opposite the next section to be filled. It is operated by a 33-horsepower gasoline engine and costs $3,600. The boom is adjustable over a range of 20 to 30 feet in steps of 2 feet.

COST OF TRENCHING BY MACHINERY

The cost of trenching by machinery depends upon a number of factors, some of which often are overlooked in considering the purchase of such a machine.

The cost of operation per day will depend upon the number of men and teams employed, the wages paid, and the amount and cost of fuel. It may be that not all of the workmen are paid when work is delayed by unfavorable conditions or for repairs; but the operator

FIGURE 8.—Machine F, for digging large trenches

and frequently his helper are employed in making the repairs, and it may often be necessary to pay the men for time lost owing to such causes as rain. Laying tile, blinding,[2] and back filling the trenches of course require further labor, which would be the same for machine work as for hand labor. In farm tile-drain contracts only three items are usually covered—trenching, laying, and blinding.

[2] "Blinding" is carefully placing the first few inches of earth around and over the tile to hold it in position and protect it while the trench is being filled.

The amount of work done per day will depend upon the soil conditions, the strength and efficiency of the machine, and the skill of the workmen. One of the most difficult soils to work is a wet, sticky clay; a sandy subsoil often will cause difficulty. The presence of

FIGURE 9.—Back filling a tile trench with team and plow

large stones or thick tree roots will of course interfere greatly, more so than with hand ditching. Very hard subsoil may make progress slow. Some of the machines have worked through 15 inches of frost, but this is severe work for any trenching machine or excavator,

FIGURE 10.—Back filling a tile trench with team and small road grader

as it subjects the machine to strains which it was not planned to withstand. Some clays become baked hard enough in dry periods to make trenching slow. These various conditions will show the weak points of a machine, and may cause a considerable variation in the

cost of operation, due to the cost of new parts and repair work and the resultant loss of time.

It may be of interest to note a few instances of work by machines. In a saturated loam soil a machine of type B dug 105 rods of trench, 14½ inches wide and 40 inches deep, in 9 hours (an unusually good day's run). In a heavy, sticky clay, another machine of the same type dug 280 rods of 12-inch trench, 3½ to 5½ feet deep, at the rate of 61 rods in 10 hours, the best day's work being 91 rods.

The matter of lost time is of great importance, for the owner usually is losing money when his machine is not digging. The portion of a year during which a machine does not work is surprisingly great, even to many drainage contractors, and will explain why

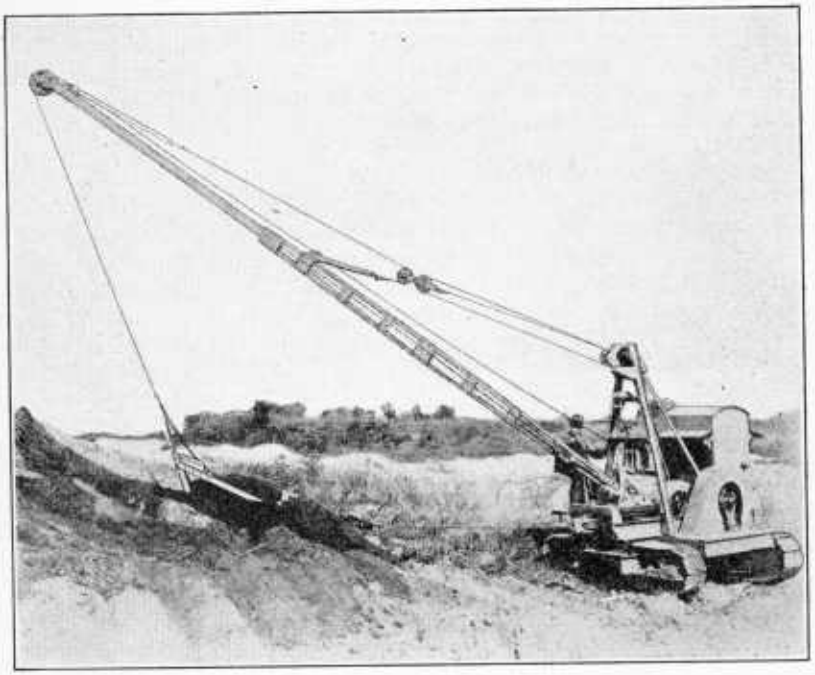

FIGURE 11.—Power-operated back filler

trenching with a machine costs so much more than one ordinarily would expect even after watching the machine work for several days under adverse conditions. While a machine is on the work there is loss due to stormy weather, and sometimes due to flooding of lowlands; there are delays for repairs, including waits for new machine parts; and there is time spent in moving from one trench to another. Interest and depreciation charges accrue during all these delays, as well as on Sundays and while the machine is being transported between jobs or lies idle waiting for new work. In the Northern States there are two to four months of the year when frozen ground and cold weather prevent work of this kind, except at rates too high for farm drainage. A contractor who has his machine actually digging 200 days in the year is fortunate.

It will be helpful to examine the record of one large contract on which the conditions were fairly good. The machine of type B arrived June 24 and began digging July 3; trenching was completed October 1. Of the 100 days the machine was on the job there were 14 Sundays, 61 days of machine work, and 25 days lost on account of repairs, rain, and miscellaneous delays. The main drain, of 5-inch to 12-inch tile, was 358 rods long and about 3.9 feet average depth. The lateral drains, of 4-inch and 5-inch tile, had a total length of 6,055 rods and an average depth of about 2½ feet. Of the 61 days of work, 12 were required for the main drain and 49 for the laterals. The average rates of progress, considering only the days of actual work, were 29.8 rods per day for the main drain and 123.6 rods per day for the laterals. If the 25 lost days be included, the working days actually used were 15 and 71 for the main and the laterals, respectively, and the average rates of digging are then computed as 23.9 and 85.3 rods per day. Coal was used as fuel, 24 short tons being required to dig 6,413 rods of ditch, or an average of 7½ pounds per rod of ditch. Repairs amounted to about 15 per cent of the cost of operation.

Another large machine [3] of type B dug from August 3 to December 7, 1918, 3,331 rods of trench in 636¾ operating hours, an average of 5.2 rods per hour. The machine was operated 10 hours a day for 6 week days. The time lost due to repairs was 221¾ hours; 9½ hours were lost on account of weather and 67 hours on account of moving between jobs on 40 different farms. The depth of trench varied as follows: 3,073.5 rods, 3 feet deep; 74 rods, 3½ feet deep; 130.5 rods, 4 feet deep; 36.5 rods, 4½ feet deep; and 18 rods, 5 feet deep. Some of the soil was quite stony. The amount spent for repairs was $241.27. The amount of gasoline used was 1,540 gallons, or an average of 1 gallon for 2.16 rods of trench dug. The gasoline cost $415.53; oil and grease cost $79.59. The machine crew consisted of one operator and one helper.

The average digging hours per 10-hour day of 15 State-owned machines operating in New York [3] during 1918 was only 4 hours, the remainder of the time being spent on repairs, delays on account of rock, and frequent moving between farms.

For tile trenching and laying by hand, where experienced men are employed, the rate of progress for one bottom man and one top man for the smaller sizes of tile laid not more than 3 feet deep is ordinarily 15 to 25 rods per day, depending largely upon soil conditions. In some sections of the country, where the use of unskilled colored labor is necessary, the same number of men will put in, even with good supervision, only 5 to 8 rods per day per man; the cost for this labor per man is, of course, considerably less than for the other.

It should be stated that there is not a great difference in the cost of trenching as between hand work and machine work. The advantages of the latter method lie in the shorter time required to install drains and in the less difficulty in securing the few workmen wanted. Men capable of satisfactorily operating a trenching machine can usually be found, even where it is impossible to secure workmen to do acceptable hand trenching without close and constant supervision.

[3] Data collected by J. R. Haswell, former drainage engineer, Bureau of Public Roads.

On the other hand, a farmer buying an expensive machine to do a small amount of work might experience some difficulty in keeping it busy with profit until it can be sold.

SELECTING A TRENCHING MACHINE

The wheel type of excavator is most generally used for installing farm drains, probably owing to a lower cost for the smaller sizes of this type than for the chain type. Machines of the latter kind have greater range in size of trench than do wheel excavators of the same weight, and seem to be better adapted for work where there is a great deal of tile 10 inches and larger. When the greater portion of a job is small tile at ordinary depths, that trenching machine should be selected which will handle best the bulk of the work. Ordinarily it is not advisable to buy a large machine when only a few hundred feet of large tile are to be laid or a small amount of deep trench is to be cut.

A trenching machine should be constructed of good materials and be well proportioned for strength. Simplicity of construction is desirable. The great loss of time on a job due to faulty operation of internal-combustion engines, and to delays for repairing broken chains, bolts, gears, and other pieces, requires the elimination of as many parts as practicable. The cost of repairs depends a great deal upon the skill and care of the operator.

In selecting any type of machine the prospective purchaser should ascertain whether the manufacturer will be able to furnish repair parts on short notice, as delays in obtaining repairs will invariably increase the cost of operation and oftentimes materially lengthen the time of operating.

While it is manifestly impracticable to make a hard-and-fast rule which the landowner may apply in selecting a trenching machine for his particular needs, the following general statements may be of assistance:

If a landowner expects to install 1,500 rods of tile drain in soil free from rock and large roots, he can afford to purchase a horse-drawn ditching plow costing from $300 to $500; and if it be assumed that the owner can sell his machine, when his ditching is completed, for $200, he would be justified in purchasing such a machine for the construction of 1,000 rods of drain. For the installation of as much as 5,000 rods of drain in a soil free from rock, stumps, and large roots the purchase of a power-driven trenching machine costing as much as $3,500 probably would be justified, on the assumption that the machine could subsequently be sold for one-half its original cost. Very economical results may be obtained where several landowners unite in the purchase of such a trenching machine as is most suitable for their combined work. The machine should preferably be run by the same operator for all the work.

Machines costing over $5,000 are suitable for contractors, owners of large farms, and others having an unusual amount of trenching to do.

Trenches should not be dug any wider than necessary, as increased width means increased load which the tile must carry. The width of trenches dug by the wheel and endless-chain types can usually be

regulated as desired. The smallest width of trench dug by drag-line excavators sometimes used in tile-trench construction is limited to the width of the bucket. This is much wider than usually is needed and consequently the supporting strength of the tile must be ascertained if machines of this type are used.

CONCLUSIONS

In comparing the real costs of different machines and implements one must consider not only the purchase price and the operating cost for fuel, oil, and labor, but also repairs, interest on the investment, and depreciation. The interest on $20 invested in a plow is not large; repairs will cost little, and the implement will last many years. For a $3,500 excavator the interest charge would be $210 per year at 6 per cent, depreciation might be $525 or more per year, and repairs would be considerable. Operating expenses and repair costs depend largely upon the amount of work done, but interest and depreciation continue whether the machine is in operation or stands idle.

On large jobs costly excavators may profitably be employed, but an inexpensive tool may be most economical for work that can well be done a little at a time when men and teams regularly employed on the farm might otherwise be idle. One of the greatest advantages of the large machines, from the farmer's viewpoint, is that the work is done rapidly; from the contractor's viewpoint there is often great advantage in using only a few men, as the employment of large numbers often involves labor difficulties.

Work is slow and costly in caving soil, in quicksand, and in sticky gumbo. Large stones, stumps, and roots cause annoyance and delay, and if in large quantity may make hand spading the cheapest method of excavation.

The data on capacities given on the preceding pages must be used with extreme caution, principally because the kind and condition of the soil and the skill of the operator affect the cost so greatly. The quality of the work also depends upon the carefulness and experience of the operator. Each purchaser must consider the limits of the work he will have to do and the conditions to be encountered, then determine what machine will best meet the requirements as a whole.

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